MATHEMATICS

EVALUATION OF HOLOGRAPHIC NEURAL NETWORKS FOR AUTOMATIC TARGET RECOGNITION

Carlos F. Borges, Associate Professor
Department of Mathematics
Sponsor: Naval Air Warfare Center-Weapons Division

OBJECTIVE: To evaluate the HNeT holographic neural network system for possible application in an automatic target recognition system.

SUMMARY: This effort began after acquiring and installing the HNeT system on a standard PC. A number of experiments were developed to test the basic functionality of the software. The first experiments focussed on evaluating the systems ability to learn complex mathematical functions from observations (a standard benchmark for artificial neural networks). Further tests were conducted with structured random data (lottery numbers) to evaluate the systems ability to exploit available structure even in a truly random environment. Finally, a series of simple target recognition experiments were performed (tracking simple geometric objects on a black background). Preliminary results are very promising as the system shows an excellent ability to identify complex scenes with very small memory requirements.

DoD KEY TECHNOLOGY AREA: Other (Image Processing)

KEYWORDS: Holographic Neural Networks, Automatic Target Recognition, Probability

TOTAL LEAST SQUARES FITTING OF ORDERED DATA WITH POLYNOMIAL SPLINES

Carlos F. Borges, Associate Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To develop fast and numerically stable algorithms for fitting polynomial splines to ordered data with minimal error in the total least-squares sense.

SUMMARY: This unfunded effort is a continuing research project. The idea is to fit parametric polynomial spline curves to ordered data to get the best possible fit. Unlike traditional least-squares methods, we assume that errors may occur in both the x and y directions. Moreover, the data is allowed to be completely general - in particular, it does not have to be functional in nature, it may overlap itself or change directions without restriction. All that is required is an ordered set of points in the plane. A variety of different approaches have been investigated and some very fast and robust algorithms for solving the problem for a single Bezier curve have been developed.

DoD KEY TECHNOLOGY AREA: Other (Scientific Computation)

KEYWORDS: Curve Fitting, Data Compression, Approximation Theory

RESEARCH IN THE STRUCTURAL DYNAMIC RESPONSE OF THE RAH-66 COMANCHE HELICOPTER

Don A. Danielson, Professor
Department of Mathematics
E. Roberts Wood, Professor
Department of Aeronautics and Astronautics
Sponsors: Comanche Program Office and Naval Postgraduate School

OBJECTIVE: Research for 1999 was focused on developing the capability of modeling the effects of a 23mm HEI (high explosive incendiary) inside the Comanche helicopter.

SUMMARY: Dytran model of an explosion in a cylindrical shell was completed.

MATHEMATICS

DoD KEY TECHNOLOGY AREA: Air Vehicles

KEYWORDS: Helicopters, Airframes, Explosions, Plasticity, Computer Software

NAVAL SPACE COMMAND DIFFERENTIAL CORRECTION PROGRAM ANALYSIS AND DOCUMENTATION

Don A. Danielson, Professor
David Canright, Associate Professor
Department of Mathematics
Sponsors: Naval Space Command and Naval Postgraduate School

OBJECTIVE: The current version of the NAVSPACECOM AUTODC program for satellite orbits has flaws but is undocumented, precluding improvement. In 1999 Professors Danielson and Canright completed the documentation of the mathematical algorithms and software structure of AUTODC.

SUMMARY: The Naval Space Command maintains a database of orbital elements for the objects in the space catalog. Professors Danielson and Canright documented the AUTODC software, which inputs new observations of a satellite and its old element set and outputs a new element set. Topics covered include: mathematics of batch least squares differential correction process, definition of fit span and passes, calculation of residuals and partials, inclusion of historical data, solution to normal equations, iterations and tolerances. Thesis student Captain Pat Marshall showed the benefits of Singular Value Decomposition when solving the normal equations. Professor Danielson presented a paper summarizing the work at the August meeting of the American Astronautical Society.

PUBLICATIONS:

Danielson, D.A, Canright, D., Perini, D.N., and Schumacher, P.W., "The Naval Space Command Automatic Differential Correction Process," *Proceedings of the AAS/AIAA Astrodynamics Conference*, 16-19 August 1999.

Danielson, D.A. and Canright, D., "Documentation of the Naval Space Command Automatic Differential Correction Process," Naval Postgraduate School Technical Report, Monterey, CA, 1999.

THESIS DIRECTED:

Marshall, P.M., "Least Squares Solutions in Statistical Orbit Determination Using Singular Value Decomposition," Master's Thesis, Naval Postgraduate School, Monterey, CA, June 1999.

DoD KEY TECHNOLOGY AREAS: Space Vehicles, Computing and Software

KEYWORDS: Satellites, Orbits, Computer Software

NUMERICAL TRAJECTORY OPTIMIZATION

Fariba Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To solve trajectory optimization problems that arise in astronautics by spectral collocation method.

SUMMARY: The purpose of this study was to investigate different spectral collocation techniques to solve a variety of trajectory optimization problems. Both Legendre and Chebyshev polynomials were used as the basis functions for approximation of the states and control variables of the underlying optimal control problems, and highly accurate results were obtained for solutions to problems in orbit maintenance, spacecraft launch and orbit transfer.

PUBLICATIONS:

Fahroo, F. and Ross, I.M., "Costate Estimation by a Legendre Pseudo-spectral Method," accepted in the *AIAA Journal of Guidance, Control, and Dynamics*, June 1999.
Fahroo, F. and Ross, I.M., "Computational Optimal Control by Spectral Collocation with Differential Inclusion," *Proceedings of Flight Mechanics Symposium*, Goddard Space Flight Center, May 1999.

THESIS DIRECTED:

Hall, A., "A MATLAB GUI for a Legendre Pseudospectral Algorithm for Optimal Control Problems," Master's Thesis, Naval Postgraduate School, June 1999.

DoD KEY TECHNOLOGY AREA: Space Vehicles

KEYWORDS: Costate Estimation, Optimal Control Theory, Legendre and Chebyshev Pseudo-spectral Method, Low-Earth Orbiting Spacecraft, Minimum Fuel Consumption

STABILITY AND CONTROL OF ACOUSTIC AND ACOUSTIC-STRUCTURE MODELS

Fariba Fahroo, Assistant Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: The goal of this project was two-fold: First, the stability of the underlying acoustic-structure models that arise in active noise control problems was studied. Then focus was on developing a mathematical framework for finding the optimal location of controls and sensors for these acoustic and acoustic-structure models.

SUMMARY: In this project, uniform exponential stability of a 2-D acoustic structure model was considered, along with the question of optimal reduction of the noise field inside a 2-D acoustic cavity by investigating optimal location of actuators. The underlying physical model consists of a rectangular cavity surrounded on 3 sides by hard walls and on one side by a flexible beam. The control strategy is to employ piezoceramic patches that induce mechanical vibrations in the beam, which in turn affect the interior noise field by the acoustic-structure interactions. Speakers that generate a secondary noise source are also used as control devices. The physical model, its numerical approximation and control strategy was presented. The effectiveness of the controls and their dependence on their location were demonstrated by numerical examples.

PUBLICATIONS:

Fahroo, F. and Wang, C., "A New Model for Acoustic-Structure Interaction and Its Exponential Stability," *Quarterly of Applied Mathematics*, Vol. LVII, No. 1, pp. 157-179, 1999.

Fahroo, F. and Wang, C., "Stability and Approximation of an Acoustic-Structure Model*,"Control of Distributed Parameter and Stochastic Systems*, Kluwer Academic Publishers, MA, pp.39-47, 1999.

Fahroo, F. and Demetriou, M., "Optimal Actuator/sensor Location for Active Noise Regulator and Tracking Control Problems," *Journal of Computational and Applied Mathematics*, Vol. 114, No. 1, pp. 37-158, 1999.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Acoustic-Structure Models

MATHEMATICS

COVARIANCE FUNCTIONS FOR 3DVAR

Richard Franke, Professor
Department of Mathematics
Sponsor: Naval Research Laboratory

OBJECTIVE: This project will be to investigate methods for approximating the covariance functions needed for the 3DVAR data assimilation algorithm developed at NRL. Use of a domain transformation to obtain vertical anisotropy has been shown to be attractive because the positive definiteness properties of the approximations are naturally extended to the function on the original domain. Horizontally varying covariance functions are required and suitable approximations for this will be investigated.

SUMMARY: This work is continuing into Calendar year 2000. Covariance functions on the sphere have been investigated using the characterization of such functions in terms of the Legendre expansion. It was found that by imposing near zero values on the fitting function for distances greater than about 0.8 radians, fits to pressure height innovations results in positive definite functions of high degree (at least degree 25) for most levels. The investigation of possible anisotropic covariance functions found that allowing the parameters of the fit (here using the special second order autoregressive covariance, or SOAR function) to vary with direction between the two observation points appears to be worth more investigation.

DOD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Numerical Weather Prediction, Data Assimilation, Covariance Functions

AN ANALYTICAL COST ESTIMATION PROCEDURE

Toke Jayachandran, Professor
Department of Mathematics
Sponsor: United States Coast Guard Research and Development Center

OBJECTIVE: Develop a mathematical/statistical methodology for performing sensitivity analyses of project cost estimates for newly proposed projects.

SUMMARY: The U.S. Coast Guard recently developed a new desktop-computer based cost analysis system for use by CG personnel to assess the cost of a new project such as the modernization of a hangar, or the acquisition of a new cutter. What was desired was a mathematical tool to perform sensitivity analyses to determine how the total cost varies as a function of the costs of lower level cost components. The tool will be useful to identify the most critical components and to determine how to proportionally allocate cost reduction to achieve a given goal. The proposed model was an adaptation of a broad generic model known as the Cobb Douglas model. The report provides recommendations on the cost components to be included in the model and methodologies for estimating the unknown parameters in the model.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Other (Costing)

KEYWORDS: Cost Assessment, Cost Components

FORMATION AND COORDINATION OF COMPLEX SYSTEMS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: United States Air Force Research Laboratory and Naval Postgraduate School

OBJECTIVE: The objectives of the project are: 1) Development of theoretical basis for the formation control of multiple vehicles, 2) Design controllers and STR projections for formations of ground vehicles, air vehicles and spacecraft, and 3) Carry out simulations and experiments to test the formation control algorithm and the designed controllers.

MATHEMATICS

SUMMARY: The PI visited AFRL on WPAFB for three months to collaborate with the AFRL research team in this subject. The first part of the research focused on the development of general mathematical model for the problem of multi-vehicle formation and its control. The second step of the research was to apply control theory to the formation of satellites.

Several feedback laws were found. Some of them have been tested by simulation. Lab experiment and more design and simulation based on a selected Air Force or NASA mission involving satellite clusters has started in 1999. We will continue this work will be continued this year and possibly another couple of more years.

DoD KEY TECHNOLOGY AREAS: Ground Vehicles, Air Vehicles, Space Vehicles

KEYWORDS: Multi-Vehicle Formation

VISIBLE SETS AND ITS MANUFACTURING APPLICATIONS

Wei Kang, Assistant Professor
Department of Mathematics
Sponsors: Ford Scientific Research Lab and Naval Postgraduate School

OBJECTIVE: The objective of the project is to find the smallest completely visible set for any geometric object. The output of the first phase of research includes: a solid theoretical foundation for the proposed problem based on topology and set theory, an algorithm based on dynamical programming to calculate the maximum indices, and to search for the minimum visible set, an illustrative industrial manufacturing example, and visible sets with engineering restrictions.

SUMMARY: An index theory was developed for the proposed problem. It numerically interprets the visibility of each side of a mechanical part. Dynamical programming is applied with the index theory to minimize the number of sensor locations to inspect every surface of a mechanical part. Also funded by Ford Scientific Lab, the Robotics Lab of MSU is building up a system with robot arms, sensors and softwares. The theory developed in this project will be implemented in the lab, and the entire system will be tested using real auto parts from the sponsor.

DoD KEY TECHNOLOGY AREA: Computing and Software

KEYWORDS: Visible Sets

GPS TRAJECTORY AVERAGING

Beny Neta, Professor
Richard Franke, Professor
Department of Mathematics
James R. Clynch, Research Professor
Department of Oceanography
Sponsors: National Imagery and Mapping Agency and Naval Postgraduate School

OBJECTIVE: The error in GPS positions consists of two primary parts, a random error assumed to have a Gaussian distribution, and a slowly varying bias dependent upon the satellites from which the GPS receiver obtains its data and their configuration. The latter changes abruptly when a different configuration of satellites is used. The objective of this investigation is to devise techniques for estimating the two errors by using multiple trajectories obtained with GPS receivers in the Precise Position System along roads, and then obtain an average trajectory.

SUMMARY: Numerous independent sets of data have been collected on a test track, on an open highway, and in an urban environment. These data were analyzed to generate an algorithm for averaging multiple tracks to improve positioning of roads. This work is based on previous results that showed that the GPS Precise Positioning System (PPS) errors are dominated by errors in the broadcast ephemeris (BCE), which are essentially constant for one BCE parameter set.

The raw positions are converted from a function of time to space curves. These are parameterized as piecewise continuous Bezier curves. These space curves fit the original data to within 0.4 m, even for complex cases. The

parameterized space curves over the same area are assumed to differ only by a bias vector. These bias vectors between pairs of space curves were used to average the bias vectors and hence the curves. The average was weighted using an algorithm common in averaging atomic clocks (N-corner hat). The averaged curves were compared to kinematic trajectories accurate at the 10 cm level. The averages of 9 measurement of a road segment, taken over 6 months, had an error about 1 m per horizontal axis level. The convergence was consistent with a Gaussian distribution.

PUBLICATION:

Clynch, J.R., Franke, R., and Neta, B., "Improvements in Dynamic GPS Positions Using Track Averaging," Naval Postgraduate School Technical Report, NPS-MA-99-004, August 1999.

OTHER:

Clynch, J.R., Franke, R., and Neta, B., "Improvements In Dynamic GPS Positions Using Track Averaging," to be presented at the Institute of Navigation National Technical Meeting, Anaheim, CA, 26-28 January 2000. Proceedings to be published.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: GPS, Bezier Curves, Bias Estimation, Curve Fitting, Track Averaging

ATTITUDE DETERMINATION

Beny Neta, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: Improved search algorithms for star identification required to determine a spacecraft attitude.

SUMMARY: Various k-vector range searching techniques are presented. These methods accomplish the range search by taking advantage of an n –long vector of integers, called the k-vector, to minimize the search time. The price is increased memory requirement for the k-vector allocation. However, it is possible to balance the extra memory required and the speed attained by choosing a step parameter, h, which samples the k-vector. A two-level k-vector technique is also presented to minimize the speed of the admissible data identification associated with a given range. The proposed methods are compared with the well known "binary search" technique, and demonstrate a high speed gain rate (from 9 to more than 40 times). Finally, just to show one of the wide-range possible applications, a method to compute the *arcsin* function, based on the k-vector technique and a look-up table, is presented.

PUBLICATION:

Mortari, D. and Neta, B., "Optimal Best-fitting of Numerical Data: Part II*," Proceedings Space Flight Mechanics*, Paper Number AAS 98-183, Breckenridge, CO, 7-10 February 1999; *Advances in the Astronautical Sciences,* Vol. 102, pp. 1185-1197, 1999.

CONFERENCE PRESENTATION:

Mortari, D. and Neta, B., "Optimal Best-fitting of Numerical Data: Part II," presented at AIAA/AAS Space Flight Mechanics Meeting, Breckenridge, CO, 7-10 February 1999.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Space Vehicles, Modeling and Simulation

KEYWORDS: Attitude Determination, Search Algorithms

MATHEMATICS

ANALYSIS OF NUMERICAL SOLUTION OF PDES

Beny Neta, Professor
Department of Mathematics
Sponsor: Unfunded

OBJECTIVE: To investigate the stability of the bilinear finite element approximation to the linearized two-dimensional advection-diffusion equation.

SUMMARY: The authors analyzed the stability of the finite element approximation to the linearized two-dimensional advection-diffusion equation. Bilinear basis functions on rectangular elements are considered. Giraldo and Neta have numerically compared the Eulerian and semi-Lagrangian finite element approximation to the advection-diffusion equation. This paper analyzes the finite element schemes used there.

PUBLICATION:

Giraldo, F.X. and Neta, B., "Stability Analysis for Eulerian and Semi-Lagrangian Finite Element Formulation of the Advection-Diffusion Equation," *Computers and Mathematics with Applications,* Vol. 38, pp. 91-103, 1999.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Finite Differences, Shallow Water, Stability Analysis, Advection-Diffusion

EFFICIENT NONLINEAR TRANSIENT DYNAMIC ANALYSIS FOR STRUCTURAL OPTIMIZATION USING AN EXACT INTEGRAL EQUATION FORMULATION

Beny Neta, Professor
Department of Mathematics
Joshua H. Gordis, Associate Professor
Department of Mechanical Engineering
Sponsor: National Science Foundation

SUMMARY: The focus of this phase of the project is the development of an improved solution algorithm for fast transient analysis of large, locally nonlinear structures using time domain structural synthesis. Time domain structural synthesis is a general and exact formulation for transient problems in structural modification, substructure coupling, and base excitation. The formulation is characterized by the governing equation of the synthesis, which is a nonlinear Volterra integral equation. The governing equation makes use of impulse response functions calculated for those coordinates of the (sub)structures subjected to forces of synthesis (e.g. modification forces, coupling forces). This physical coordinate formulation provides for a largely unrestricted and exact model reduction, in that only those coordinates of interest need be retained in the synthesis. We document the development of several algorithms intended to improve upon the original algorithm developed by Gordis. The last algorithm developed meets the stated goals of the project. This algorithm is a newly developed recursive, block-by-block convolution solution to the governing nonlinear integral equation. As is demonstrated with a simple but realistically large nonlinear base excitation problem (51,500 DOF finite element model), the new algorithm provides a 78% reduction in time required for the nonlinear transient base excitation solution, as compared with traditional direct integration calculated using a widely-used commercial finite element program. This very large savings in computer time is obtained for a single analysis, i.e. assuming no prior calculations have been made for the impulse response functions of the (sub)structures. The new algorithm provides an even greater reduction in computer time for all subsequent analyses. As shown in the example problem, once all required impulse response functions have been calculated, the nonlinear base isolation solutions calculated using the new recursive, block-by-block convolution algorithm take approximately 7 seconds, as compared with the direct integration solution which takes approximately 30 minutes. This rapid reanalysis capability will facilitate the development of numerical optimization for the design of nonlinear isolation.

PUBLICATIONS:

Gordis, J.H. and Neta, B., "Efficient Nonlinear Transient Dynamic Analysis for Structural Optimization Using an Exact Integral Equation Formulation," Naval Postgraduate School Technical Report, NPS-ME-99-009, 1999.

Gordis, J.H. and Neta, B., "Fast Transient Analysis for Locally Nonlinear Structures by Recursive Block Convolution," *Proceedings 70th Shock and Vibration Symposium*, Albuquerque, NM, 15-19 November 1999.

CONFERENCE PRESENTATION:

Neta, B., "Fast Transient Analysis for Locally Nonlinear Structures by Recursive Block Convolution," 70th Shock and Vibration Symposium, Albuquerque, NM, 15-19 November 1999.

DoD KEY TECHNOLOGY AREAS: Computing and Software, Modeling and Simulation

KEYWORDS: Finite Elements, Structural Synthesis, Convolution, Block-by-block

NUMERICAL MODELING OF SONAR TRANSDUCERS AND ARRAYS

Clyde L. Scandrett, Associate Professor
Department of Mathematics
Steven R. Baker, Associate Professor
Department of Physics
Sponsor: Office of Naval Research

OBJECTIVE: To produce the most compact, efficient, yet accurate, computational method for the performance modeling of randomly- and arbitrarily-densely-packed volumetric active sonar arrays, one that is practical to employ on a desktop microcomputer.

SUMMARY: An investigation into the applicability and accuracy of Pritchard's approximation for closely packed transducer arrays was undertaken. A new, "modal" Pritchard approximation was developed, based upon normal modes of the acoustic medium, and was tested for arrays of acoustically hard spheres to ascertain its accuracy in determining the mutual acoustic radiation impedance between array elements.

A second goal for FY99 was to re-compute the single-scattering T-matrix for an elastic spherical shell, using a new mesh which was specifically built so it could be refined using ATILA's built-in mesh generator, MOSAIQUE. The new mesh was expected to show better results than previous meshes, for the same level of refinement, as it has more favorable element aspect ratios at the poles. This was accomplished, but the results were not satisfactory.

PUBLICATION:

Scandrett, C. and Baker, S., "Pritchard's Approximation in Array Modeling," Naval Postgraduate School Technical Report, NPS-UW-99-001, October 1999.

THESIS DIRECTED:

Day, J.L., "A Modal Approximation for the Mutual Radiation Impedance for Spherical Sources and Acoustic Wave Scattering Using an Improved ATILA Finite Element Code," Master's Thesis, Naval Postgraduate School, September 1999.

DoD KEY TECHNOLOGY AREA: Sensors

KEYWORDS: Active Sonar, Transducer, Array, Modeling, Finite Element

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MATHEMATICS

Fahroo, F. and Demetriou, M., "Optimal Location of Actuators for Control of a 2-D Structural Acoustic Model," *Proceedings of Conference on Decision and Control*, Phoenix, AZ, December 1999.

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Hamzi, B., Barbot, J.P., and Kang, W., "Bifurcation for Discrete Time Parameterized Systems with Uncontrollable Linearization," *Proceedings of IEEE Conference on Decision and Control*, Phoenix, AZ, 7-10 December 1999.

Hamzi, B., Barbot, J.P., and Kang, W., "Normal Forms for Discrete Time Parameterized Systems with Uncontrollable Linearization," *Proceedings of IEEE Conference on Decision and Control*, Phoenix, AZ, 7-10 December 1999.

Kang, W., Xi, N., and Tan, J., "Analysis and Design of Non-time Based Motion Controller for Mobile Robots," *Proceedings of IEEE Conference on Robotics and Automation*, Detroit, MI, pp. 2964-2969, 12-14 May 1999.

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Kang, W. and Xi, N., "Non-Time Referenced Tracking Control with Application in Unmanned Vehicle," *Proceedings of IFAC World Congress of Automatic Control*, Beijing, China, 5-9 July 1999.

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Scandrett, C. and Baker, S., "Pritchard's Approximation in Array Modeling," Naval Postgraduate School Technical Report, NPS-UW-99-001, October 1999.